A DEVICE AND METHOD FOR FATIGUE TESTING OF MATERIALS

The present invention relates to a device and method for fatigue testing of materials and in particular relates to a device and method for combined low cycle fatigue and high cycle fatigue testing of materials.

Gas turbine engine fan blades, compressor blades and turbine blades are subjected to a combination of low cycle fatigue and high cycle fatigue stresses in operation of the gas turbine engine. These low cycle fatigue and high cycle fatigue stresses have a detrimental effect on the integrity of the fan blades, compressor blades and turbine blades. The low cycle fatigue (LCF) is a result of the centrifugal force experienced by the fan blades, compressor blades and turbine blades as they rotate about the axis of the gas turbine engine. The high cycle fatigue (HCF) is a result of aerodynamic and other vibration excitation of the fan blades, compressor blades and turbine blades.

The centrifugal force on a fan blade may exert a mean stress of the order of 500 MPa, or more, resulting in low cycle fatigue. The high cycle fatigue fundamental mode frequencies may vary from about 50 Hz for a fan blade to several kHz, for example 2 to 3 kHz, for a high-pressure compressor blade.

The high cycle fatigue damage quickly builds up due to the relatively large number of cycles in relatively short periods of time. The damaging effect of the mechanical cycles is exacerbated by the thermal cycles to which the gas turbine engine is subjected in operation.

In order to design fan blades, compressor blades and turbine blades which are resistant to fatigue, a good understanding of the combination of the steady and alternating stresses a blade may tolerate for any vibration mode that may be excited in operation is required.

The fatigue testing of materials under conditions representative of gas turbine engine operating conditions is difficult to achieve for blade aerofoil shapes and blade root shapes. Conventional low cycle (LCF), high cycle fatigue (HCF) and fatigue crack growth (FCC) have been used to provide mechanical data on simple specimen shapes. Direct comparison between simple specimen shapes and real blades have revealed marked differences in fatigue life. Consequently safety factors, typically 50%, are commonly applied to the fatigue data.

Thus there is a requirement to produce fatigue testing data from specimens whose geometry and state of stress is comparable to real blades in order to aid the design of blades resistant to fatigue or to more accurately determine the working life of real blades.

Accordingly the present invention seeks to provide a novel device for fatigue testing of materials which reduces, preferably overcomes, the above mentioned problems.

Accordingly the present invention provides a device for fatigue testing of materials comprising a frame, first and second clamping means for holding a specimen to be tested, mounting means to mount the first and second clamping means on the frame, the mounting means vibrationally isolating the first and second clamping means from the frame, means to move at least one of the first and second clamping means to apply in operation a low cycle load on the specimen, means to measure the low cycle load, vibration excitation means acoustically coupled to one of the first and second clamping means to apply in operation a high cycle load on the specimen, means to measure the high cycle load, detector means to detect vibration of the specimen and to produce an electrical signal, control means arranged to receive the electrical signal, the control

means determining the resonant frequency of the specimen from the electrical signal and sending a signal to the vibration excitation means to maintain the high cycle load at the resonant frequency of the specimen and means to store data of the test.

Preferably the mounting means comprises first leaf spring to mount the first clamping means and a second leaf spring to mount the second clamping means.

Preferably the resonant frequency of the mounting means and first and second clamping means is arranged to be lower than the resonant frequency of the specimen.

Preferably the vibration excitation means comprises an actuator.

Preferably the actuator is arranged to generate frequencies in the range 50Hz to 5kHz.

Preferably the actuator is acoustically coupled to the first or second clamping means via a drive rod.

Preferably the actuator is an electrodynamic, piezoelectric or a magnetostrictive actuator.

Preferably there are heating means to heat the specimen.

Preferably the heating means comprises a furnace arranged to surround the specimen.

Preferably electrical insulating means electrically insulate the frame from the specimen.

Preferably there are means to supply an electrical current through the specimen, probes arranged on opposite sides of a crack on the specimen to produce a second electrical signal, means to determine crack growth rate arranged to receive the second electrical signal and to determine the rate of crack growth in the specimen.

Preferably the means to store data stores the life of the specimen to the initiation of the first crack.

Preferably the means to store data stores the life of the specimen to failure.

The present invention also provides a method of fatigue testing of materials using a device comprising a frame, first and second clamping means for holding a specimen to be tested, mounting means to mount the first and second clamping means on the frame, the mounting means vibrationally isolating the first and second clamping means from the frame, means to move at least one of the first and second clamping means to apply in operation a low cycle load on the specimen, means to measure the low cycle load, electrical insulating means electrically insulate the frame from the specimen, vibration excitation means acoustically coupled to one of the first and second clamping means to apply in operation a high cycle load on the specimen, means to measure the high cycle load, detector means to detect vibration of the specimen and to produce an electrical signal, control means arranged to receive the electrical signal, the control means determining the resonant frequency of the specimen from the electrical signal and sending a signal to the vibration excitation means to maintain the high cycle load at the resonant frequency of the specimen and means to store data of the test, the method comprising

(a) applying a low cycle load and/or a high cycle load to the specimen,

(b) maintaining the vibration of the specimen at its resonant frequency,

(c) detecting a drop in the resonant frequency of the specimen indicative of the initiation of a crack in the specimen,

(d) stopping the test and locating the crack,

(e) attaching probes to the specimen at each side of the crack, the probes are arranged to produce a second electrical signal,

(f) supplying an electrical current through the specimen,

(g) resuming the test and maintaining the vibration of the specimen at its resonant frequency until failure of the specimen occurs,

(h) determining the rate of crack growth in the specimen from the second electrical signal and/or determining the life of the specimen to failure.

The method may comprise applying tensile load and bending mode vibrations on the specimen.

The method may comprise applying tensile load and torsion mode vibrations on the specimen.

The specimen may be aerofoil shaped.

The method may comprise heating the specimen.

The method may comprise determining the life of the specimen to the initiation of the first crack.

Step (d) may comprise heating the specimen to oxidise and colour the surfaces of the crack on the specimen.

Step (b) may comprise maintaining the vibration of the specimen at a predetermined amplitude of vibration.

The method may comprise determining the amount of energy required to vibrate the specimen at the predetermined amplitude of vibrations at the resonant frequency of the specimen.

Preferably the specimen comprises a damping treatment or a damping coating.

The present invention also provides a device for fatigue testing of materials comprising a frame, first and second clamping means for holding a specimen to be tested, mounting means to mount the first and second clamping means on the frame, the mounting means vibrationally isolating

the first and second clamping means from the frame, means to move at least one of the first and second clamping means to apply in operation a low cycle load on the specimen, means to measure the low cycle load, electrical insulating means electrically insulate the frame from the specimen, vibration excitation means acoustically coupled to one of the first and second clamping means to apply in operation a high cycle load on the specimen, means to measure the high cycle load, detector means to detect vibration of the specimen and to produce an electrical signal, control means arranged to receive the electrical signal, the control means determining the resonant frequency of the specimen from the electrical signal and sending a signal to the vibration excitation means to maintain the high cycle load at the resonant frequency of the specimen, probes are provided on the specimen in operation and are arranged to produce a second electrical signal, means to supply an electrical current through the specimen, means to determine crack growth rate arranged to receive the second electrical signal and to determine the rate of crack growth in the specimen and/or determining the life of the specimen to failure.

Preferably there may be means to heat the specimen to oxidise and colour the surfaces of the crack on the specimen. The control means may determine the amplitude of vibration of the specimen from the electrical signal and sends a signal to the vibration excitation means to maintain the high cycle load at a predetermined amplitude of vibration. The control unit may determine the amount of energy required to vibrate the specimen at the predetermined amplitude of vibration at the resonant frequency of the specimen. The specimen may comprise a damping treatment or a damping coating.

The present invention will be more fully described by way of example with reference to the accompanying drawings in which:-

Figure 1 shows a device for fatigue testing of materials according to the present invention.

Figure 2 is a schematic diagram of the device for fatigue testing of materials shown in figure 1.

Figure 3 shows a perspective view of a portion of the device shown in figure 1.

A device 10 for fatigue testing of materials is shown in figures 1 to 3. The device 10 for fatigue testing of materials, for example a specimen 12, comprises a frame 14, first clamping means 16, second clamping means 18, first mounting means 20 and second mounting means 22. The first and second clamping means 16 and 18 hold opposite longitudinal ends of the specimen 12. The first and second clamping means 16 and 18 and the ends of the specimen 12 have co-operating features to allow the first and second clamping means 16 and 18 to grip the specimen 12. The co-operating features for example may be threaded apertures in the first and second clamping means 16 and 18 and threaded ends of the specimen 12 or alternatively dovetail or firtree connections. The first and second clamping means 16 and 18 have a relatively large mass and rotational inertia and act substantially, or approximately, as nodal points during vibration of the specimen 12 in its bending modes.

The first and second mounting means 20 and 22 mount the first and second clamping means 16 and 18 on the frame 14. The first and second mounting means 20 and 22 vibrationally isolate the first and second clamping means 16 and 18 from the frame 14. The first and second mounting means 20 and 22 for example comprise leaf springs, which are shown more fully in figure 3. The leaf springs are

much wider than they are thick. The resonant frequency of the first and second clamping means 16 and 18 and the first and second mounting means 20 and 22 is arranged to be lower than the resonant than the resonant frequency of the specimen 12.

The leaf springs 20 and 22 may be connected to the frame 14 by a solid connection or by a resilient connection to minimise the transmission of bending moments to the frame 14. The resilient connection may comprise further leaf springs.

An actuator 24 is provided to move the first and second clamping means 16 and 18 relative to each other. In this example the actuator 24 is arranged to move the first clamping means 16 and first mounting means 20 relative to the second clamping means 18, the second mounting means 22 and the frame 14 to apply in operation a low cycle load on the specimen 12. The low cycle load may be either a tension load or a compression load. The actuator 24 may be an electromechanical screw drive, an electric motor, hydraulic piston or any other suitable actuator. The actuator 24 may apply loads up to 100kN or greater.

A shaker 26, or actuator, is acoustically coupled to one of the first and second clamping means 16 and 18. In this example the shaker 26 is acoustically coupled to the second clamping means 18, by a drive member 28 for example a drive rod and/or an excitation spring, to apply in operation a high cycle load on the specimen 12. The actuator 26 may be an electrodynamic, a piezoelectric or a magnetostrictive actuator. The actuator 26 is arranged to produce vibrations in the frequency range 50Hz to 5kHz. The leaf springs of the first and second mounting means 20 and 22 are arranged such that the width of the leaf springs extends transversely to the direction in which the shaker 26 applies the load on the specimen 12. The stiffness of

the drive member 28 is selected so that the mass of the shaker 26 and the drive member 28 have a natural resonant frequency close to the bending mode of the specimen 12.

One or more electrical insulators 30 are provided to electrically insulate the frame 14 from the specimen 12. The electrical insulators 30 are provided between the first mounting means 20 and the actuator 24 and between the second mounting means 22 and the frame 14. The electrical insulator 30 comprises any suitable material which prevents the flow of an electrical current. The first and second mounting means 20 and 22 are bolted to the actuator 24 and the frame 14 by electrically insulating bolts.

One or more detectors 32 are arranged to detect displacement, or vibration, of the specimen 12. The detectors 32 are proximity probes, accelerometers or optical displacement probes. The detectors 32 are electrically connected to a data input and control signal output unit 34 by electrical connectors 36.

A stabilised electrical power supply 33 is electrically connected to the opposite ends of the specimen 12 by electrical connectors 35. The power supply 33 is arranged to supply a current of 50 to 100A through the specimen 12. The power supply 33 is arranged to supply a DC current which is pulsed periodically to prevent heating of the specimen. Alternatively the power supply 33 is arranged to supply an AC current which prevents heating of the specimen 12. A load cell 41 is provided on the frame 14 to measure the mean axial stress on the specimen 12. The load cell 41 is electrically connected to the data input and control signal output unit 34 by electrical connectors 43.

During testing electrical potential drop probes 38 are welded to the specimen 12 on each side of a crack. The potential drop probes 38 are electrically connected to the

data input and control signal output unit 34 by electrical connectors 40.

The data input and control signal output unit 34 supplies the electrical signals from the detectors 32, the probes 38 and the load cell 41 to a main control unit 42 by an electrical connector 44.

The main control unit 42 supplies control signals to a control unit 50 for the actuator 24 through an electrical connector 46, the data input and control signal output unit 34 and an electrical connector 48. The control unit 50 supplies control signals to the actuator 24 through an electrical connector 52.

The main control unit 42 supplies control signals to a waveform generator 54 for the shaker 26 through the electrical connector 46, the data input and control signal output unit 34 and an electrical connector 56. The waveform generator 54 is connected to the shaker 26 through an electrical connector 58, a power amplifier 60 and an electrical connector 62.

The main control unit 42 comprises for example a personal computer or a computer. The main control unit 42 is arranged to store data and is connected to a monitor 64 and a printer 66.

The main control unit 42 is arranged to analyse the electrical signals from the detectors 32 to determine the resonant frequency of vibration of the specimen 12. The main control unit 42 has simulated test data and a relationship to determine the high cycle fatigue stresses/loads applied to the specimen 12 from the measure of displacement provided by the detectors 32. The main control unit 42 is arranged to analyse the electrical signals from the probes 38 to determine the electrical potential drop across a crack in the specimen 12.

The specimen 12 is enclosed in a furnace, not shown, to heat the specimen 12 to a higher temperature representative of the temperature of operation of a real component. The furnace is arranged to heat the specimen up to any suitable temperature, for example up to 700°C or higher.

The main control unit 42 is also connected to the control unit of the furnace to maintain the specimen 12 at a predetermined temperature.

In operation to fatigue test a specimen 12 the ends of a specimen 12 to be tested are placed in the first and second clamping means 16 and 18. The specimen 12 substantially reproduces geometric features found on a real component, for example a gas turbine engine fan blade, compressor blade or turbine blade and is manufactured from the same material, for example the same alloy. The specimen 12 shown reproduces the fillet radius connection between the aerofoil and a platform of compressor blade.

The main control unit 42 sends electrical signals to the control unit for the furnace to heat the specimen 12 to a predetermined temperature or to maintain the specimen 12 at ambient temperature.

The main control unit 42 sends electrical signals to the control unit 50 and the waveform generator 54 to apply low cycle loads, high cycle loads or a combination of low cycle loads and high cycle loads on the specimen 12.

The detectors 32 send electrical signals corresponding to the amplitude and frequency of vibration of the specimen 12 to the main control unit 42. The main control unit 42 analyses the electrical signals and determines the resonant frequency of the specimen 12. The main control unit 42 then sends further electrical signals to the control unit 50 and/or the waveform generator 54 to maintain the

frequency of vibration of the specimen 12 at its resonant frequency to generate a crack in the specimen 12.

The main control unit 42 continues to analyse the electrical signals from the detectors 32 to determine if a crack has been generated in the specimen 12. The main control unit 42 determines that a crack has been generated in the specimen 12 when the resonant frequency of the specimen drops to a lower frequency. Once a crack has been generated in the specimen 12 the main control unit 42 stops the fatigue test and the position of the crack in the specimen 12 is determined.

The position of the crack in the specimen 12 is determined by for example applying a dye to the surface of the specimen 12 and then removing the dye. The specimen 12 is inspected visually to find remains of the dye in the crack and hence the position of the crack in the specimen 12. Alternatively other methods of determining the position of the crack may be used.

The potential drop probes 38 are welded to the specimen 12 on the opposite sides of the crack.

The fatigue test is restarted and the main control unit 42 again sends electrical signals to the control unit 50 and/or the waveform generator 54 to maintain the frequency of vibration of the specimen 12 at its resonant frequency. The main control unit 42 may maintain the frequency of vibration at the resonant frequency even during changes in the resonant frequency of the specimen 12 due to growth of the crack, until the specimen 12 fractures. Alternatively the main control unit 42 may not maintain the frequency of vibration at the resonant frequency of the specimen 12.

The main control unit 42 analyses the electrical signals from the potential drop probes 38 to determine the rate of crack growth in the specimen 12. The main control

unit 42 is arranged to store the data and/or display the data on the monitor 64 and/or on the printer 66.

The main control unit 42 is arranged to determine and store the low cycle loads and the high cycle loads applied to the specimen 12 over time and thus produce a history of the loads applied to the specimen 12. The load history may include the number of cycles to failure of the specimen 12 and/or the number of cycles to the start of a crack in the specimen 12. The load history may include the magnitude of the loads and the frequency of the vibrations. The main control unit 42 is arranged to display the data on the monitor 64 and/or on the printer 66.

In a further method of operation to fatigue test a specimen 12, the same procedure is followed until a crack has been generated in the specimen 12 and the main control unit 42 stops the fatigue test. The specimen 12 is removed from the fatigue testing device 10 and is heated at a high temperature for a short period of time to oxidise and colour the fracture surfaces of the specimen 12.

The specimen 12 is placed into the fatigue testing device 10 and the potential drop probes 38 may or may not be welded to the specimen 12. The fatigue test is started and the main control unit 42 again sends signals to the control unit 50 and/or waveform generator 54 to maintain the frequency of vibration of the specimen 12 at its resonant frequency until the specimen 12 fractures or fails completely. The fracture surfaces of the specimen 12 are analysed to enable accurate modelling of crack formation and to distinguish crack initiation from crack propagation. The oxidised and coloured fracture surfaces are those formed during crack initiation and the unoxidised and coloured uncoloured fracture surfaces are those formed during crack growth/propagation.

In a further method of operation to fatigue test a specimen 12. The main control unit 42 also analyses the electrical signals to determine the amplitude of vibration of the specimen 12. The main control unit 42 then sends further signals to the control unit 50 and/or the waveform generator 54 to maintain the frequency of vibration of the specimen 12 at its resonant frequency to maintain the amplitude of vibration of the specimen 12 at a predetermined amplitude until the specimen 12 fractures or fails completely. The main control unit 42 determines the amount of energy required to vibrate the specimen 12 at the predetermined amplitude of vibration at the resonant frequency, particularly in a bending mode vibration. It is possible to provide coatings of different damping materials or provide different damping treatments on identical specimens 12 to determine which damping material or damping treatment provides the most damping and/or to rank the damping materials and damping treatments in order of increasing damping coefficient. This is achieved by comparing the amount of energy required to vibrate the specimens 12 at the predetermined amplitude of vibration at the resonant frequency. This is particularly beneficial for determining suitable damping materials for fan blades, compressor blades or turbine blades. Also by testing the specimens 12 until they fail it is possible to determine the effect of the damping coating, or damping treatment, on the fatigue strength of fatigue life of the specimen.

The low cycle load applied may be a tensile load or a compressive load. The high cycle load may be a torsion load or a bending load. The leaf springs of the mounting means may be redesigned to have low torsional stiffness to allow testing of the torsional modes of the specimen. A torsional load is applied by adjusting the position of the shaker. In this case the shaker is mounted of axis to

apply a load to the second clamping means and a second shaker may be used to cancel the direct load applied to the second clamping means.

It may also be possible to put strain gauges on the specimen and relate the strain to the stress. This is more accurate but more expensive than using a load cell. It may be possible to locate one or more strain gauges at the axial mid point of the specimen and one ore or more strain gauges near the point where the specimen is going to fail. The exact positioning of the strain gauges depends on the geometry of the specimen.

The advantages of the invention are that it is able to fatigue test specimens which simulate the shape of real components under conditions experienced by real components. The ability to measure the rate of crack growth under low cycle load and high cycle load conditions and at elevated temperature is very important because the combination of a tensile load and bending/torsion mode vibration closely simulates the stresses experienced by real components in operation. The invention also allows the study of the influence of foreign object damage on the propagation of cracks and the integrity of components. The invention provides fatigue and crack propagation data which was not previously available. The use of this data will enable improvements in the design of components due to a clearer understanding of the behaviour of components and the safety margins. The invention enables the testing of components with identical shapes but manufactured from different materials and/or different processes to determine the effect the different materials and/or different processes have on the life of the component. The invention allows a better estimation of component life, safe stress limits

Although the invention has been described with reference to testing gas turbine engine blades it may be

used for testing steam turbine blades or other components or articles or sub-elements of components or articles.